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SOP-SGCE-GL-012402
BASELINE

STANDARD OPERATING PROCEDURE

ED27
LOAD CONTROL AND MEASUREMENTS TEAM

STRUCTURAL LOADS TEST MEASUREMENT ACQUISITION SYSTEM (SLTMAS)

CONVERSION EQUATIONS

LOAD CONTROL AND MEASUREMENTS TEAM
STRUCTURAL AND DYNAMICS TESTING GROUP
STRUCTURES, MECHANICS, AND THERMAL DEPARTMENT

APPROVING AUTHORITY

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Raw Data to Voltage (mV) Conversion Equations

Amplified ADC raw data counts are converted into floating-point values that represent the original transducer voltage output (mV) as shown below.

$$v = \frac{BD}{G_1 G_2}$$

where

$v =$ transducer output (mV),
$B =$ bit weight of ADC (0.3125 mV/bit),
$D =$ raw data from ADC (counts),
$G_1 =$ preamp gain,
$G_2 =$ postamp gain.

Determination of Transducer Excitation

Many transducer EU (Engineering Unit) conversion equations depend upon the excitation voltage (or, in some cases, current) supplied to the transducer. The excitation value for each transducer can be determined in one of three ways. (The method to be used for each transducer is listed in the Measurements table CalType field for that transducer.) A description of each method follows:

Current Sense Resistor (ExcMvCurrSense)

This method is accurate only for transducers with a constant known impedance. First, the current in the transducer excitation circuit is determined using a current sense resistor in the circuit:

$$I_\circ = \frac{V_{cs}}{R_{cs}}$$

where

$I_\circ =$ calculated excitation current (mA)
$V_{cs} =$ measured voltage across current sensing resistor (mV)
$R_{cs} =$ precision current sensing resistor value (Ω)

The current can then be multiplied by the transducer impedance to obtain an excitation voltage:

$$V_\circ = I_o R$$

where

$V_\circ =$ calculated excitation voltage (mV)
$I_\circ =$ calculated excitation current (mA)
$R =$ cell resistance (Ω)

Operator-Specified (ExcMvSpecified)

For transducers with integral excitation regulation, no additional excitation determination is necessary. Also, for some transducer types, the exact excitation can only be obtained by a voltage measurement at the transducer. In these cases, the operator must specify the transducer excitation:

$V_\circ =$ regulated (or measured offline) excitation voltage (mV)

Current Sense for Constant Current Excitation (ExcMaCurrSense)

Transducers requiring constant current excitation (e.g. RTDs, potentiometers) typically use the current-sensing resistor method to determine the value of the excitation current. Input hardware configuration for these transducers provides a more accurate current-sensing circuit in addition to the one used for constant voltage excited transducers. Care must be exercised in the entry of the associated instrumentation database parameters.

$$I_\circ = \frac{V_{cs}}{R_{cs}}$$

where

$I_\circ =$ calculated excitation current (mA)
$V_{cs} =$ measured voltage across current sensing resistor (mV)
$R_{cs} =$ precision current sensing resistor value (Ω)

Measurements and Calculated Values

A “measurement” VID is the default EU conversion assigned to each channel in a database. The conversion equation for each measurement VID transforms the raw digital counts from a single input channel, plus the instrumentation parameters for that channel, into a single output value with engineering units of measure. Note the one-to-one correspondence between channels and measurement VIDs.

A “calculated value” VID is an EU conversion that is based not on one channel, but on up to twenty other VIDs. The conversion equation for each calculated VID transforms the EU values from specified measurement VIDs and/or other calculated VIDs, plus up to twenty constant coefficients, into a single output value with engineering units of measure. Note that the number of calculated VIDs in a database has no limit, but that a calculated VID dependent upon other VIDs should be placed *after* those other VIDs in the conversion sequence.

A Zero Engineering Units Reference (*ZEUR)* scan is an EU scan taken at an appointed zero reference test condition. *ZEUR* scans may be taken at any point during testing, with the most recent (or “active”) *ZEUR* scan subtracted from all subsequent converted scans. Subtracting *ZEUR* forces VIDs to have a zero value at the reference condition, so that subsequent scans represent only the delta value actually caused by the test load. The first *ZEUR* scan for each database is initialized to zero, and the *ZEUR* feature may be enabled/disabled for each VID at any time prior to each *ZEUR* scan. For a VID with *ZEUR* disabled, the calculated value from a new *ZEUR* scan is discarded, and that VID's value from the previous *ZEUR* scan is propagated to the new *ZEUR* scan.

The Engineering Units Offset factor (*EUO*) is a constant value (in engineering units) that may be added to a measurement. It is *not included*, however, when a *ZEUR* scan is converted. (For example, a VID with an *EUO* of 350 and *ZEUR* enabled will read 350 immediately after a *ZEUR* scan, instead of the usual zero reading.)

Each VID also has associated with it a six-character string representing its units, and an integer representing the number of decimal places for tabular display.

Measurement Conversion Types

List of Measurement Conversion VID types

Equation	**VID type code**
Linear	MeasLinear
Polynomial	MeasPoly
Table Lookup	MeasMvToEuTable
RTD (Resistance Temperature Device)	MeasRTD
Strain Gage (Quarter Bridge)	MeasQtrBrg

Measurement conversion types, with associated parameters and conversion equations, are shown below.

Linear (MeasLinear)

$$EU = \frac{e_1}{SV_o \cdot 10^{-3}} - ZEUR + EUO$$

where

EU = engineering unit result

e_1 = RDH scan data (mV)

S = sensitivity ((mV / V of excitation) / EU)

V_o = exact transducer excitation (mV)

EUO = engineering unit offset constant (EU)

$ZEUR$ = zero engineering units reference (EU)

Polynomial (MeasPoly)

$$EU = a_0 + a_1\left(\frac{e_1}{V_o \cdot 10^{-3}}\right) + a_2\left(\frac{e_1}{V_o \cdot 10^{-3}}\right)^2 + \cdots + a_9\left(\frac{e_1}{V_o \cdot 10^{-3}}\right)^9 - ZEUR + EUO$$

where

EU = engineering unit result
e_1 = RDH scan data (mV)
V_o = exact transducer excitation (mV)
a_0 = polynomial coefficient (EU)
a_1 = polynomial coefficient (EU/(mV/V of excitation))
$\vdots$
a_9 = polynomial coefficient (EU/(mV/V of excitation)^9)
EUO = engineering unit offset constant (EU)
$ZEUR$ = zero engineering units reference (EU)

The actual computation is carried out in nested polynomial form to avoid the time-consuming calculation of the exponential powers shown above. (Execution time is reduced because fewer multiply operations are needed.) The nested form of the equation is:

$$EU = a_0 + \left(\frac{e_1}{V_o \cdot 10^{-3}}\right)\left[a_1 + \left(\frac{e_1}{V_o \cdot 10^{-3}}\right)\left[a_2 + \left(\frac{e_1}{V_o \cdot 10^{-3}}\right)\left[a_3 + \cdots + \left(\frac{e_1}{V_o \cdot 10^{-3}}\right)a_9\,]]]]]\right]\right]\right] - ZEUR + EUO$$

mV-to-EU Table Lookup (MeasMvToEuTable)

The EU value for each lookup table VID is found by linear interpolation within the appropriate EU lookup table for that VID. Lookup tables reside in a database file separate from the instrumentation database (because almost all lookup tables, such as those for thermocouples and RTDs, apply universally, while instrumentation databases are test-specific). The path to the lookup table database file can be set or modified within the test mode application.

The lookup table must consist of three fields: “dblMv”, “dblEu”, and “dblSlope”. In each table record, “dblEu” is the EU value corresponding to “dblMv” millivolt output from the transducer. The value “dblSlope” is pre-calculated as shown below to speed interpolation during run-time. The records must be sorted in order of ascending “dblMv”. To convert each scan, a seek is performed in the lookup table for the first record such that

$e_1 \leq$ dblMv where e_1 = transducer output (mV).

If the record found is referred to as record n, then

$$EU = S_n(e_1 - mV_n) + EU_n - ZEUR \ \ + EUO$$

where

EU = engineering unit result
e_1 = RDH scan data (mV)
mV_n = first value > e_1 in lookup table (mV)
EU_n = corresponding EU value in lookup table (EU)
S_n = corresponding slope value in lookup table (EU/mV)
EUO = engineering unit offset constant (EU)
$ZEUR$ = zero engineering units reference (EU)

The derivation for the slope and EU conversion is as follows. Assume the transducer output e_1 satisfies $mV_{n-1} \le e_1 \le mV_n$. Then record n will satisfy "Seek $e_1 \le$ dblMv " and be the table record used to find the EU value corresponding to e_1.

	mV_1	EU_1	S_1	
	:	:	:	
	mV_{n-1}	EU_{n-1}	S_{n-1}	
phantom row (	e_1	EU	S	)
	mV_n	EU_n	S_n	
	:	:	:	
	mV_{last}	EU_{last}	S_{last}	

To linearly interpolate between rows n and $(n\text{-}1)$, use the formula

$$\frac{EU_n - EU}{EU_n - EU_{n-1}} = \frac{mV_n - e_1}{mV_n - mV_{n-1}}$$

and solve for EU:

$$EU = \left(\frac{EU_n - EU_{n-1}}{mV_n - mV_{n-1}}\right)(e_1 - mV_n) + EU_n$$

Note that the first quantity in brackets is independent of the scan data, and thus can be a one-time calculation before the test:

$$S_n = \left(\frac{EU_n - EU_{n-1}}{mV_n - mV_{n-1}}\right)$$

If $e_1 > mV_{last}$, the "Seek $e_1 \le$ dblMv " operation fails and EU is assigned a huge positive value to alert the user. If $e_1 \le mV_1$, the conversion occurs normally, but the improperly defined S_1 defaults to a huge positive value, driving EU to a huge negative value to alert the user.

Resistance Temperature Detector (RTD) Table Lookup (MeasRTD)

The millivolt output from an RTD must be converted into a resistance value; the resistance value is then used as the entry into a lookup table.

$$R = \frac{e_1}{I_o}$$

where

$R =$ calculated resistance of RTD element (Ω) < not stored >
$e_1 =$ RDH scan data (mV)
$I_\circ =$ constant excitation current (mA) .

For RTDs, the lookup table must consist of three fields: “dblOhms”, “dblEu”, and “dblSlope”. In each table record, “dblEu” is the EU value corresponding to “dblOhms” resistance from the RTD element. The value “dblSlope” is pre-calculated to speed interpolation during run-time. The records must be sorted in order of ascending “dblOhms”. To convert each scan, a seek is performed in the lookup table for the first record such that

$R \leq$ dblOhms where R = RTD element resistance (Ω).

If the record found is referred to as record n, then

$$EU = S_n(R - R_n) + EU_n - ZEUR + EUO$$

where

$EU =$ engineering unit result
$R =$ RTD element resistance (Ω)
$R_n =$ first value $> R$ in lookup table (Ω)
$EU_n =$ corresponding EU value in lookup table (EU)
$S_n =$ corresponding slope value in lookup table (EU/Ω)
$EUO =$ engineering unit offset constant (EU)
$ZEUR =$ zero engineering units reference (EU)

As with mV-to-EU table lookup, the slope is independent of the scan data, and thus can be a one-time calculation before the test:

$$S_n = \left(\frac{EU_n - EU_{n-1}}{R_n - R_{n-1}} \right)$$

If $R > R_{last}$, the “Seek $R \leq$ dblOhms” operation fails and EU is assigned a huge positive value to alert the user. If $R \leq R_1$, the conversion occurs normally, but the improperly defined S_1 defaults to a huge positive value, driving EU to a huge negative value to alert the user.

Quarter Bridge Strain Gage (MeasQtrBrg)

$$EU = \left(\frac{2\cdot 10^6}{G_{fv}}\right)\frac{e_1(2R_g + R_{11})}{R_g(V_\circ - 2R_g^2 A e_1 - e_1)}$$

where

$$\begin{aligned}
EU &= \text{engineering unit result (always in microstrain, } me\text{)}\\
e_1 &= \text{RDH scan data (mV)}\\
G_{fv} &= \text{nominal gage factor supplied by the vendor}\\
V_\circ &= \text{exact gage excitation (mV)}\\
R_g &= \text{nominal gage resistance supplied by the vendor } (\Omega)\\
R_{11} &= \text{1 - wire lead from gage to bridge completion block } (\Omega)\\
A &= \frac{1}{2R_g(R_g + R_{11}) + 2R_{12}(2R_g + R_{11})}\\
R_{12} &= \text{1 - wire lead from bridge completion block to excitation power supply } (\Omega)\\
(R_{12} &= \text{0 for RDH internal bridge completion)}\\
EUO &= \text{engineering unit offset constant (EU)}\\
ZEUR &= \text{zero engineering units reference (EU)}
\end{aligned}$$

The above equation is implemented in the form below for faster computation:

$$EU = \frac{e_1}{d_0 - e_1 d_1} - ZEUR + EUO$$

where d_0 and d_1 can be pre-calculated from

$$\begin{aligned}
d_0 &= \frac{V_o R_g G_{fv}}{d_2}\\
d_1 &= \frac{2G_{fv}R_g\left(R_g^2 A + 0.5\right)}{d_2}\\
d_2 &= 2\cdot 10^6(2R_g + R_{11})
\end{aligned}$$

Calculated Conversion Types

List of Calculated Conversion VID types

Equation	**VID Type Code**
Polynomial	CalcPoly (not to be confused with MeasPoly)
Weighted Total	CalcWeightedTot
2-Norm	Calc2Norm
Arc	CalcArc
Absolute Value	CalcAbsVal
Digital Channel Bit	CalcBit
Multiply/Divide	CalcMultDivide
Parametric Exponential	CalcParamExp
Square Root	CalcSqrt
Extended von Mises	CalcExtVM
Constant	CalcConstant (has its own table)
Temperature-Corrected Leg Strains	CalcSgTempCorr (has its own table)
Rosettes:	(Have their own table)
Biaxial Rosette (0°, 90°)	CalcBiax
Triaxial Rosette (0°, 45°, 90°)	CalcTriax45 (legs numbered counterclockwise)
Triaxial Rosette (0°, 45°, 90°)	CalcTriax45CW (legs numbered clockwise)
Triaxial Rosette (0°, 60°, 120°)	CalcTriax60

Calculated conversion types, with associated equations, are shown below. The following parameters are included (not all equations use all 20 coefficients or input VIDs):

$$
\begin{aligned}
EU &= \text{engineering unit result} \\
VID_0 &= \text{Input VID 0 (EU)} \\
VID_1 &= \text{Input VID 1 (EU)} \\
&\vdots \\
VID_{19} &= \text{Input VID 19 (EU)} \\
a_0 &= \text{Constant coefficient 0} \\
a_1 &= \text{Constant coefficient 1} \\
&\vdots \\
a_{19} &= \text{Constant coefficient 19} \\
EUO &= \text{engineering unit offset constant (EU)} \\
ZEUR &= \text{zero engineering units reference (EU)}
\end{aligned}
$$

Note that constant VIDs *ONE* and *ZERO* (with values of 1 and 0, respectively) are always available as placeholders to "de-generalize" the calculation equations. For example, a simple multiplication of two VIDs can be set up in a *CalcMultDivide* VID by assigning input VID_2 = ONE.

Polynomial (CalcPoly)

$$EU = a_0 + a_1(VID_0) + a_2(VID_0)^2 + \cdots + a_9(VID_0)^9 - ZEUR + EUO$$

Weighted Total (CalcWeightedTot)

$$EU = a_0(VID_0) + a_1(VID_1) + a_2(VID_2) + \cdots + a_{19}(VID_{19}) - ZEUR + EUO$$

2-Norm (Calc2Norm)

$$EU = \sqrt{a_0(VID_0)^2 + a_1(VID_1)^2 + a_2(VID_2)^2 + \cdots + a_{19}(VID_{19})^2} - ZEUR + EUO$$

Arc (CalcArc)

$$EU = \frac{180}{p}\frac{VID_0}{a_0} - ZEUR + EUO$$

Absolute Value (CalcAbsVal)

$$EU = \left|VID_0\right| - ZEUR + EUO$$

Digital Channel Bit (CalcBit)

$$EU = (2^{a_0} \ \& VID_0) >> a_0$$

where & = bit-wise AND operator
>> = right-shift operator
a_0 = integer from 0 to 15 (bit of interest)
EU = value of bit of interest (0 or 1)

(Note that *EUO* and *ZEUR* are ignored for this type)

Multiply/Divide (CalcMultDivide)

$$EU = \frac{a_0(VID_0)(VID_1)}{VID_2} - ZEUR + EUO$$

Parametric Exponential (CalcParamExp)

$$EU = \left(a_0(VID_0) + a_1(VID_1)\right) \cdot \exp\{a_2(VID_2)\} - ZEUR + EUO$$

Square Root (CalcSqrt)

$$EU = a_0(VID_0)\sqrt{\frac{a_1(VID_1)}{a_2(VID_2)}} - ZEUR + EUO$$

Extended von Mises (CalcExtVM)

$$EU = \sqrt{X_1^2 + X_2^2 + a_6 X_1 X_2 + a_7 X_3^2} - ZEUR + EUO$$
$$X_1 = a_0(VID_0) + a_1(VID_1)$$
$$X_2 = a_2(VID_0) + a_3(VID_1)$$
$$X_3 = a_4(VID_0) + a_5(VID_1)$$

The following three calculated conversion types have dedicated tables in the instrumentation database.

Constant (CalcConstant)

This is one of three types that have dedicated tables in the instrumentation database. The constant VIDs “ZERO” and “ONE” are automatically included in every conversion sequence.

$EU = a_0$ (Note that *EUO* and *ZEUR* are ignored for this type)

where

$a_0 =$ constant value of VID (EU) <CalcConstant!dblConstantValue>

Temperature-Corrected Leg Strains (CalcSgTempCorr)

This is one of three types that have dedicated tables in the instrumentation database.

$$EU = \frac{\hat{e}_I - \left(\frac{2}{\hat{G}_f}\right)\hat{e}_{app}}{1 + \frac{\%\Delta}{100}} - ZEUR + EUO$$

where

$$\hat{e}_I = \text{output of strain Measurement VID } (me) < \text{VID} \rightarrow \text{CalcSgTempCorr!szStrainVID} >$$
$$\hat{e}_{app} = \text{output of Calculated VID } (me) < \text{VID} \rightarrow \text{CalcSgTempCorr!szAppStrainVID} >$$
$$\%\Delta = \text{output of Calculated VID} < \text{VID} \rightarrow \text{CalcSgTempCorr!szGFVarVID} >$$
$$\hat{G}_f = \text{desensitized gage factor for strain gage VID} < \text{CalcSgTempCorr!dblDesensGF} >$$
$$EUO = \text{engineering unit offset constant (EU)}$$
$$ZEUR = \text{zero engineering units reference (EU)}$$

Rosettes – Introduction

This is one of three types that have dedicated tables in the instrumentation database.

“Rosettes” are combinations of two or three strain gage “legs” oriented in a specific geometry. The geometry for a rosette determines its calculation type. Parameters for all four-rosette calculation types are stored in the “**CalcRosettes**” table. There are multiple EU output values for each rosette calculation type. The geometries and associated calculation types for SLTMAS-PC are as follows:

Rosette Geometry	**SLTMAS Type**	**# Output VIDs**
Rectangular Biaxial (0°- 90°, aligned with principal axes)	CalcBiax	11
Rectangular Triaxial (0°- 45°- 90° counterclockwise)	CalcTriax45	15
Nonstandard Rectangular Triaxial (0°- 45°- 90° clockwise)	CalcTriax45CW	15
Delta Triaxial (0°- 60°- 120°)	CalcTriax60	10

Each “leg” of a rosette must appear in the conversion list as an individual measurement VID of type *MeasQtrBrg* with units of “microstrain” (με); **if desired**, each leg measurement VID can be further input into a strain gage temperature-correction calculated VID (type *CalcSgTempCorr*). Only these two types of VIDs will serve as valid “leg” input VIDs for rosette calculation types. Fields szLeg1VID, szLeg2VID, and szLeg3VID specify the individual strain gage leg VIDs that are input into the rosette calculations for a given rosette VID. The *CalcTriax45* equations assume leg 1 is oriented with respect to the reference axis by 0°, leg 2 by 45°, and leg 3 by 90°. The *CalcBiax* equations assume that *the reference axis is principal*, and that leg 1 is oriented with respect to the reference axis by 0°, leg 2 by 90°. The *CalcTriax45CW* equations assume leg 1 is oriented with respect to the reference axis by 0°, leg 2 by (- 45°), and leg 3 by 90°. The *CalcTriax60* equations assume leg 1 is oriented with respect to the reference axis by 0°, leg 2 by 60°, and leg 3 by 120°.

The following terms appear in the equations below for each of the four rosette calculated VID types (note that *EUO* and *ZEUR* are ignored for rosette types):

$$e_i = \text{Leg } i \text{ strain VID } (me)$$
$$Kt_i = \text{Leg } i \text{ transverse sensitivity}$$
$$n = \text{Poisson's ratio VID}$$
$$E = \text{Young's modulus VID (force/area)}$$

Rosettes – Biaxial (*CalcBiax*)

Rosette Value	**Code Appended to VID**	**Example: VIDs Generated for Rosette VID B_AFT_131**	**Corresponding Symbol in Equations Below**
Transverse Sensitivity-Corrected Leg Strains	-0M	B_AFT_131-0M	e_{t1}
	-90M	B_AFT_131-90M	e_{t2}
Leg Stresses	-0S	B_AFT_131-0S	s_1
	-90S	B_AFT_131-90S	s_2
Principal Strains	-MAXM	B_AFT_131-MAXM	e_{max}
	-MINM	B_AFT_131-MINM	e_{min}
	-SHRM	B_AFT_131-SHRM	g_{max}
	-ANG	B_AFT_131-ANG	q_p
Principal Stresses	-MAXS	B_AFT_131-MAXS	s_{max}
	-MINS	B_AFT_131-MINS	s_{min}
	-SHRS	B_AFT_131-SHRS	t_{max}

Transverse Sensitivity-Corrected Leg Strains

$$e_{t1} = \frac{e_1(1-vK_{t1}) - K_{t1}e_2(1-vK_{t2})}{1-K_{t1}K_{t2}}$$

$$e_{t2} = \frac{e_2(1-vK_{t2}) - K_{t2}e_1(1-vK_{t1})}{1-K_{t1}K_{t2}}$$

Leg Stresses

$$s_1 = \frac{E\cdot 10^{-6}}{1-v^2}\left(e_{t1} + ve_{t2}\right)$$

$$s_2 = \frac{E\cdot 10^{-6}}{1-v^2}\left(e_{t2} + ve_{t1}\right)$$

Principal Strains

$$e_{max} = \max(e_{t1}, e_{t2})$$

$$e_{min} = \min(e_{t1}, e_{t2})$$

$$g_{max} = e_{max} - e_{min}$$

$$q_p = 0^\circ$$

Principal Stresses

$$s_{\max} = \frac{E \cdot 10^{-6}}{1 - v^2}\left(e_{\max} + ve_{\min}\right)$$

$$s_{\min} = \frac{E \cdot 10^{-6}}{1 - v^2}\left(e_{\min} + ve_{\max}\right)$$

$$t_{\max} = \frac{E \cdot 10^{-6} g_{\max}}{2(1 + v)}$$

Rosettes – Rectangular Triaxial Standard (*CalcTriax45*) and Clockwise (*CalcTriax45CW*)

Rosette Value	**Code Appended to VID**	**Example: VIDs Generated for Rosette T_FWD_43597**	**Corresponding Symbol in Equations Below**
Transverse Sensitivity Correction	-0M	T_FWD_43597-0M	e_{t1}
	-45M	T_FWD_43597-45M	e_{t2}
	-90M	T_FWD_43597-90M	e_{t3}
Leg Stresses	-0S	T_FWD_43597-0S	s_1
	-45S	T_FWD_43597-45S	s_2
	-90S	T_FWD_43597-90S	s_3
Principal Strains	-MAXM	T_FWD_43597-MAXM	e_{max}
	-MINM	T_FWD_43597-MINM	e_{min}
	-SHRM	T_FWD_43597-SHRM	g_{max}
	-ANG	T_FWD_43597-ANG	q_p
Principal Stresses	-MAXS	T_FWD_43597-MAXS	s_{max}
	-MINS	T_FWD_43597-MINS	s_{min}
	-SHRS	T_FWD_43597-SHRS	t_{max}
Von Mises and Orthogonal Shear	-VM	T_FWD_43597-VM	s_{vm} (von Mises yield criterion)
	-ORT	T_FWD_43597-ORT	t_{orth} (orthogonal shearing stress referenced to gage legs)

Transverse Sensitivity-Corrected Leg Strains

$$e_{t1} = \frac{e_1(1-vK_{t1}) - K_{t1}e_3(1-vK_{t3})}{1-K_{t1}K_{t3}}$$

$$e_{t2} = \frac{e_2(1-vK_{t2})}{1-K_{t2}} - \frac{K_{t2}\left[e_1(1-vK_{t1})(1-K_{t3}) + e_3(1-vK_{t3})(1-K_{t1})\right]}{(1-K_{t1}K_{t3})(1-K_{t2})}$$

$$e_{t3} = \frac{e_3(1-vK_{t3}) - K_{t3}e_1(1-vK_{t1})}{1-K_{t1}K_{t3}}$$

Leg Stresses

$$s_1 = \frac{E \cdot 10^{-6}}{1-v^2}\left(e_{t1} + ve_{t3}\right)$$

$$s_2 = \frac{E \cdot 10^{-6}}{1-v^2}\left[e_{t2} + n\left(e_{t1} - e_{t2} + e_{t3}\right)\right]$$

$$s_3 = \frac{E \cdot 10^{-6}}{1-v^2}\left(e_{t3} + ve_{t1}\right)$$

Principal Strains

$$e_{\max} = \frac{A+B}{2}$$
$$e_{\min} = \frac{A-B}{2}$$
$$g_{\max} = B$$
$$q_p = \frac{1}{2}\tan^{-1}\left(\frac{D}{C}\right)$$
$$A = e_{t1} + e_{t3}$$
$$B = \sqrt{C^2 + D^2}$$
$$C = e_{t1} - e_{t3} \quad \text{for CalcTriax45 (legs numbered counterclockwise -- standard)}$$
$$C = e_{t3} - e_{t1} \quad \text{for CalcTriax45CW (legs numbered clockwise -- nonstandard)}$$
$$D = 2e_{t2} - A$$

Principal Stresses

$$s_{\max} = \frac{E \cdot 10^{-6}}{1-v^2}\left(e_{\max} + ve_{\min}\right)$$
$$s_{\min} = \frac{E \cdot 10^{-6}}{1-v^2}\left(e_{\min} + ve_{\max}\right)$$
$$t_{\max} = \frac{E \cdot 10^{-6} g_{\max}}{2(1+v)}$$

Von Mises and Orthogonal Shear

$$s_{vm} = \sqrt{s_{\max}^2 - s_{\max}s_{\min} + s_{\min}^2}$$
$$t_{orth} = t_{\max}\sin(2q_{\mathrm{p}})$$

Rosettes – Delta Triaxial (*CalcTriax60*)

Rosette Value	Code Appended to VID	Example: VIDs Generated for Rosette DT_LEFT_992	Corresponding Symbol in Equations Below
Transverse Sensitivity Correction	-0M	DT_LEFT_992-0M	e_{t1}
	-60M	DT_LEFT_992-60M	e_{t2}
	-120M	DT_LEFT_992-120M	e_{t3}
Leg Stresses (Not available)			
Principal Strains	-MAXM	DT_LEFT_992-MAXM	e_{max}
	-MINM	DT_LEFT_992-MINM	e_{min}
	-SHRM	DT_LEFT_992-SHRM	g_{max}
	-ANG	DT_LEFT_992-ANG	q_{p}
Principal Stresses	-MAXS	DT_LEFT_992-MAXS	s_{max}
	-MINS	DT_LEFT_992-MINS	s_{min}
	-SHRS	DT_LEFT_992-SHRS	t_{max}

Transverse Sensitivity-Corrected Leg Strains

$$e_{t1} = \frac{A - B}{G}$$

$$e_{t2} = \frac{C - D}{G}$$

$$e_{t3} = \frac{E - F}{G}$$

$$A = e_1(1 - vK_{t1})(3 - K_{t2} - K_{t3} - K_{t2}K_{t3})$$

$$B = 2K_{t1}\left[e_2(1 - vK_{t2})(1 - K_{t3}) + e_3(1 - vK_{t3})(1 - K_{t2})\right]$$

$$C = e_2(1 - vK_{t2})(3 - K_{t3} - K_{t1} - K_{t3}K_{t1})$$

$$D = 2K_{t2}\left[e_3(1 - vK_{t3})(1 - K_{t1}) + e_1(1 - vK_{t1})(1 - K_{t3})\right]$$

$$E = e_3(1 - vK_{t3})(3 - K_{t1} - K_{t2} - K_{t1}K_{t2})$$

$$F = 2K_{t3}\left[e_1(1 - vK_{t1})(1 - K_{t2}) + e_2(1 - vK_{t2})(1 - K_{t1})\right]$$

$$G = 3K_{t1}K_{t2}K_{t3} - K_{t1}K_{t2} - K_{t2}K_{t3} - K_{t3}K_{t1} - K_{t1} - K_{t2} - K_{t3} + 3$$

Leg Stresses

Not available.

Principal Strains

$$e_{\max} = A + B$$
$$e_{\min} = A - B$$
$$g_{\max} = 2B$$
$$q_p = \frac{1}{2}\tan^{-1}\left(\frac{D}{C}\right)$$
$$A = \frac{e_{t1} + e_{t2} + e_{t3}}{3}$$
$$B = \sqrt{C^2 + D^2}$$
$$C = e_{t1} - A$$
$$D = \frac{e_{t2} - e_{t3}}{\sqrt{3}}$$

Principal Stresses

$$s_{\max} = \frac{E \cdot 10^{-6}}{1 - v^2}\left(e_{\max} + ve_{\min}\right)$$
$$s_{\min} = \frac{E \cdot 10^{-6}}{1 - v^2}\left(e_{\min} + ve_{\max}\right)$$
$$t_{\max} = \frac{E \cdot 10^{-6} g_{\max}}{2(1 + v)}$$